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Future opportunities for commercialization of the microgravity environment will depend upon the success of basic research projects performed in space. Significant demands for manufacturing opportunities are unlikely in the near term. The microgravity environment is to be considered primarily as a tool for research and secondarily as a manufacturing site. This research tool is unique, valuable, and presently available to U.S. investigators only through resources provided by NASA. The United States has an obligation to facilitate corporate research, maintain a flexible international policy, foster use of and assure access to a wide variety of facilities, and develop a posture of national and international leadership in and stewardship of research and materials processing in the microgravity environment. The National Research Council's Committee on Industrial Applications of the Microgravity Environment recommends six actions that strengthen this posture, including the formation of an authoritative organization to oversee the implementation of a vigorous program of basic microgravity research and its industrial applications.

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Industrial Applications of the Microgravity Environment

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Industrial Applications of the Microgravity Environment

SPACE APPLICATIONS BOARD
COMMISSION ON ENGINEERING AND TECHNICAL SYSTEMS
NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY PRESS
WASHINGTON, D.C.
1988

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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The National Research Council was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Frank Press and Dr. Robert M. White are chairman and vice chairman, respectively, of the National Research Council.

This study by the Space Applications Board was conducted under Contract No. NASW-4154 with the National Aeronautics and Space Administration.

SPACE APPLICATIONS BOARD

Future opportunities for commercialization of the microgravity environment will depend upon the success of basic research projects performed in space. Significant demands for manufacturing opportunities are unlikely in the near term. The microgravity environment is to be considered primarily as a tool for research and secondarily as a manufacturing site. This research tool is unique, valuable, and presently available to U.S. investigators only through resources provided by NASA. The United States has an obligation to facilitate corporate research, maintain a flexible international policy, foster use of and assure access to a wide variety of facilities, and develop a posture of national and international leadership in and stewardship of research and materials processing in the microgravity environment. The National Research Council's Committee on Industrial Applications of the Microgravity Environment recommends six actions that strengthen this posture, including the formation of an authoritative organization to oversee the implementation of a vigorous program of basic microgravity research and its industrial applications.

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Preface

The advent of the space station era, with the launching of the Mir Space Station and the approval of the National Aeronautics and Space Administration (NASA) plan for an International Space Station, has placed microgravity research at center stage in space science. Microgravity research includes industrial applications of the microgravity environment. The promise of eliminating buoyancy-driven forces (sedimentation, convection) and exaggerating weak surface forces attracts industrial researchers in such fields as metals and alloys, glass and ceramics, fluid dynamics, electronics, biotechnology, combustion science, and polymer science.

For two decades, NASA has conducted a research program in "Materials Processing in Space," now termed "Microgravity Science and Applications," which is also the name of a Division within its Office of Space Science and Applications (OSSA). Two other NASA Offices support microgravity research programs: the Office of Commercial Programs (OCP) and the Office of Aeronautics and Space Technology (OAST). Although the Congress has shown considerable interest in this field, although there are a few hundred scientists interested in microgravity research, and although hyperbole abounds concerning its promise, U. S. productivity has been limited. The Space Applications Board (SAB) was asked by OSSA to review this field and to provide a realistic assessment of the potential for transfer of technology to U.S. industry while also examining economic and management aspects of U.S. programs. The SAB responded by constituting the Committee on Industrial Applications of the Microgravity Environment, consisting of members of the SAB and appointed representatives of industry, government, and universities. After its approval by the National Research Council, this committee held four meetings — two dedicated to information gathering and two dedicated to preparation of this report, the foundation of which is six major recommendations to strengthen the future of industrial applications of the microgravity environment in the United States.

Throughout the course of planning and execution of the committee's duties, the members of the committee gave this responsibility substantial priority in their busy lives and devoted correspondingly serious attention to it likewise, and those who were invited to speak to the committee prepared their presentations with utmost care and expressed themselves with exceptional frankness. The report that follows does not express an easily derived consensus of the committee; the words that appear in the body of the report are the result of a combination of lengthy debate, frank expressions of opinion, attacks and parries, and eventual thorough agreement. I am most grateful for the sustained patience and energy of the committee in arriving at this product, and I express the committee's strong sentiment in thanking the staff of the Space Applications Board, Dr. William H. Michael, Jr., Ms. Vki Marrero, Ms. Amy Janik, and Mr. David Johnson. Drs. Robert Pedraglia of McDonnell Douglas Corporation, and Christopher Podsiadly of Minnesota Mining & Manufacturing Company played an important role in the committee's deliberations, and Mr. Courtland S. Lewis made careful notes of the committee's progress and aided immensely in creating the language of the report.

Paul Todd
Chairman

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Abstract

Future opportunities for commercialization of the microgravity environment will depend upon the success of basic research projects performed in space. Significant demands for manufacturing opportunities are unlikely in the near term. The microgravity environment is to be considered primarily as a tool for research and secondarily as a manufacturing site. This research tool is unique, valuable, and presently available to U.S. investigators only through resources provided by NASA. The United States has an obligation to facilitate corporate research, maintain a flexible international policy, foster use of and assure access to a wide variety of facilities, and develop a posture of national and international leadership in and stewardship of research and materials processing in the microgravity environment. The National Research Council's Committee on Industrial Applications of the Microgravity Environment recommends six actions that strengthen this posture, including the formation of an authoritative organization to oversee the implementation of a vigorous program of basic microgravity research and its industrial applications.

Report of the Committee on Industrial Applications of the Microgravity Environment

1. Introduction

Throughout the history of humankind, materials have been the fundamental facilitating or "gateway" technology that has made other technological advances possible. From wood and stone, to iron, to bronze and steel, to silicon semiconductors and ceramic superconductors, progress in the development of materials has been the foundation for the ascent of man. As mankind now moves out into a fuller exploration and use of space, the development of materials for application in space will become as important as the development of materials for terrestrial, commercial applications. We will have to learn how to live with, work in, and productively utilize the characteristics of the microgravity environment. Space provides the medium for what may be some of the most novel and important advances in materials and processes that we are likely to see in our lifetimes.

The National Research Council's Space Applications Board was asked by the National Aeronautics and Space Administration's Office of Space Science and Applications to undertake a study of the NASA microgravity program, with emphasis on the potential for transfer of the program results to industry. An outcome of the review was expected to be a realistic evaluation of the industrial potential of space processing and space processing research. The management and economic aspects of space processing were also to be evaluated. The Space Applications Board responded to this request by establishing a temporary Committee on Industrial Applications of the Microgravity Environment, charged to conduct research on these questions and to prepare a report. Over the past decade, related subjects have been addressed by other bodies. The Committee on the Industrial Applications of the Microgravity Environment used the reports of those groups as background for its deliberations and research while avoiding duplication of the efforts of those bodies. Therefore, some of the findings and recommendations that follow are expressed in the context of earlier reports, with which the committee has chosen to agree or disagree. The body of the report is brief and is written in the spirit of an executive summary, with supporting appendices corresponding to each recommendation presented at the end of the report.

The goal of the committee's report, and the purpose of its recommendations, is to ensure that the United States is well positioned to obtain and hold a leadership role in the useful application of the microgravity environment and to maintain a high international profile in this highly visible arena.

2. A Leadership Role for NASA in Microgravity Research

Space provides humankind with a new and unique environment for research. The near-weightless, or microgravity, environment of space offers a new variable for research on materials and industrial processes. For the indefinite future, progress in science and technology will benefit greatly from the exploration of this new variable and the fuller understanding of other variables (especially those masked by gravity) that affect processes on earth. NASA is itself a major user and patron of advanced materials, and NASA holds the keys to the space environment.

> *NASA should take a leadership role in ensuring that the valuable microgravity environment is used wisely, aggressively, and fairly in pursuit of basic science and its application to the nation's interests.*

Microgravity materials science and applications has three objectives: (1) basic research on materials and materials processing, (2) *in situ* (i.e., in-space) processing focused on the use of materials in space (such as the welding of space structures and the lubrication of space machines) and (3) manufacturing of products in space for return to earth. Nearly all of the activity in the field to date has focused on the first two objectives, yet the perceived promise of the field has often focused on the third activity, manufacturing. A variety of authoritative reports on this subject have stressed that the most significant near-term promise lies in the first two areas, research and in-space processing technology, rather than in the manufacturing of products. We concur with this finding. However, industrial development draws on knowledge developed from basic research. In the absence of an adequate pool of knowledge derived from microgravity research, it is impossible to predict the future industrial applications of microgravity research.

In view of present resource and knowledge limitations, we recommend that NASA focus its current microgravity program on basic materials science, processing research, and in-space processing technology, rather than on manufacturing.

3. Working With U.S. Industry

As directed by the Space Act of 1958 (as amended), a major goal in NASA's microgravity program has been to enlist the support of U.S. industry. Industry will participate for long-term strategic reasons if the risks and barriers are sufficiently low. At present, U.S. industry perceives little near-term profit incentive for manufacturing in space. However, industrial involvement in this very early period of basic research undoubtedly will hasten the day when the knowledge gained from that research contributes to U.S. industrial competitiveness. The government should take steps to minimize the various institutional impediments to flight experimentation.

Given the scarcity of near-term profitable ventures requiring the microgravity environment, and the desirability of having industry and government working together in this field (including research interactions between NASA and industries), we recommend that the U.S. Government and NASA encourage firms to participate in microgravity research and technology development (either alone or in the form of consortia, such as those sponsored by the Centers for Commercial Development of Space) by actively supporting such industrial research and by reducing the barriers to that participation.

Faster document processing, streamlined peer review, reduced barriers to project development, and reliable access to microgravity are some of the greatest needs. It is also important to strengthen the communication between NASA and the nation's industrial research community (through regular exchange of information and personnel assignments) regarding advances and opportunities in the microgravity field.

4. International Cooperation

U.S. national self-interest requires that international policy with respect to microgravity research become more flexible. Japan, Germany, France, and the European Space Agency are all vigorously pursuing research in the microgravity field, and they have substantial microgravity research budgets. INTOSPACE is Europe's aggressive corporation for the commercialization of microgravity. Furthermore, many Japanese companies in the relevant fields have established a Space Department (or the equivalent) with full-time research staff. Cooperation with these allies on microgravity research would be highly advantageous to the United States and will be facilitated by their planned participation in the Space Station, to give one example. In particular, NASA should review its current restrictions on foreign participation as partners with U.S. firms and institutions in the Centers for the Commercial Development of Space to ensure that they are in accord with U.S. interests. In many cases, we have more to gain than to lose through the participation of foreign companies.

Cooperation with nations other than our allies could also offer benefits. The fundamental nature of microgravity research in space provides us with a unique opportunity to share information on advances in a field whose potential applications are still far in the future. For example, in its Salyut and Mir space stations, the Soviet Union, a most successful spacefaring nation, has conducted over 2,000 microgravity experiments, giving it a well-developed experience and knowledge base in microgravity research. The People's Republic of China also has recently begun an active program of microgravity research on materials. As the magnitude of space projects grows, there will be goals that no single nation can meet with its own resources.

We recommend that the U.S. government enhance the collaboration between U.S. and foreign microgravity scientists *to the greatest extent consistent with U.S. interests. NASA could facilitate this collaboration by the following means: (1) allow foreign-owned companies from friendly nations to participate in NASA microgravity research consortia, and (2) create a Task Force-type group to explore mechanisms for interacting internationally to maximize scientific return while protecting U.S. interests.*

5. Access to Space

The one irreplaceable resource for the pursuit of research in microgravity is access to space. The hiatus in the Space Shuttle program has created severe problems in this field, as it has in many others that depend on regular access to the space environment. The committee emphasizes the urgent need to rebuild the momentum, quality, and enthusiasm in NASA's microgravity research program; yet we recognize that this is particularly difficult to do given the lack of flight opportunities. Existing facilities for pursuing microgravity research in earth-based facilities are inadequate, so that preparation of experiments for future spaceflight opportunities is difficult.

To provide the greatest possible number of experiment opportunities under the currently constrained circumstances, NASA should maximize opportunities for access to and use of the microgravity environment to prepare for research aboard the Space Station. Opportunities are needed for both manned and unmanned research. The means of access should include expendable launch vehicles (ELVs) with recoverable capsules, extended duration orbiters, and proposed free-flyers of various designs. Thus, we add our voice to the growing chorus of those urging NASA's development of a mixed fleet of craft for access to space, using ELVs for launching unmanned experiment packages and the Shuttle for those that require human presence. Non-orbital facilities such as drop towers, tubes and capsules, aircraft, and sounding rockets should also be employed. Creative approaches such as "piggybacking" microgravity experiments on other payloads, or even designing them into satellites with other primary missions, should be pursued. Extensive use of the full range of facilities is necessary to provide microgravity researchers with an interim means of developing equipment and experiment protocols in preparation for the effective use of the Space Station during the next decade. The current paucity of flight opportunities could prevent the nation from taking full advantage of future long-duration microgravity facilities;

performing this microgravity research in advance would help to fill that gap.

> *We recommend that NASA maximize access to microgravity by fully utilizing the widest possible range of microgravity facilities. In addition, we strongly recommend that research efforts focus on the development of improved ways of pursuing remote, unmanned microgravity research (i.e., research methodologies, sensors, effectors, etc.). Over time, the microgravity research community should attempt to reduce the percentage of experiments that require continuous manned tending, and those microgravity experiments that must be manned should be considered by NASA as Primary Payloads, to the extent possible.*

In order to achieve this enhanced access, NASA should:

(1) allocate to microgravity research a significant portion of the total time in orbit for experiments requiring full-time man tending;

(2) give microgravity experiments requiring man tending Primary Payload status to assure that Orbiter resources (e.g., power, heating, cooling) are available to them and that the availability of such resources is not modified in experiment-threatening ways. For example, Microgravity Science Laboratories (MSL's) should be treated as Primary Payloads;

(3) develop Extended Duration Orbiter (EDO) and free-flier platform capabilities as soon as possible to assure that tested experiments and facilities are available for utilization on advanced long-duration spacecraft.

In this regard, it is essential to ensure that the planned Space Station is designed to flexibly support a full range of changing microgravity research needs over the life of the facility. Designing in that capability will require that NASA have a general concept of the future microgravity research program while providing adequate flexibility for the evolution of that program.

6. Utilizing the Nation's Microgravity Resources

The nation's microgravity resources consist of: microgravity research facilities of every type, both earth- and space-based; NASA's research and development activities and infrastructure; industrial and academic capabilities and expertise; and external funding. Collectively, they represent a unique resource. At present, those national resources allocated to microgravity research are mostly found within NASA, where (as was pointed out in the 1987 report[1] of the (NASA) Microgravity Materials Science Assessment Task Force) they are distributed throughout the organization. On the basis of a recommendation made in that report, NASA has taken steps to coordinate microgravity project R&D sponsored by the different divisions within NASA. The committee applauds the intent of that recommendation and urges that, while improving coordination, NASA take care not to sacrifice the diversity (and hence creativity) of microgravity research in the interest of simplified management, and also that NASA assure that the special needs of corporate participants are adequately served.

To maximize the impact that national resources can have on the expansion of knowledge and its utilization requires that the resources and the projects in which they are employed be wisely coordinated and strongly managed not only within NASA but also throughout the government and in cooperation with all sectors of the economy. Furthermore, the committee wishes to call the attention of NASA to the fact that the microgravity science research program requires stable conditions in both management and policy. We assume that NASA will be providing strong leadership for microgravity research. In addition, we believe that policy, goal-setting, and strategy decisions bearing on progress in the microgravity field should be addressed through a high-level federal advisory board. Represented on that board should be not only NASA, the current "provider" of most resources and facilities for microgravity research, but also other potential providers as well as the potential users. These latter include industries such as pharmaceutical, electronics, metallurgy, and ceramics, and government agencies such as the National Science Foundation and the Departments of Commerce (NOAA and the NBS), Transportation, Energy, and Health and Human Services (which includes the National Institutes of Health). Successful past experience with the National Advisory Committee on Aeronautics

[1] This report is often referred to as the "Dunbar Report," after the Task Force chair, astronaut Bonnie J. Dunbar. See Appendix A, Section 4, for complete bibliographic citation.

(NACA) serves as an example of excellence in transferring research results to industry. That transfer was accomplished through industry participation on the advisory council from the earliest planning stages on.

Because of the limited access to this unique research environment, and because of the range of interested parties, we recommend that the federal government establish a senior advisory board composed of representatives of industry, academe, and interested government agencies. The mission of this board would be to maximize multi-sectoral participation in the civilian microgravity program, and to facilitate the implementation of the foregoing recommendations of this committee. Such a board could be housed in an existing policy office of the Federal Administration, with NASA as its leading agency.[2]

[2]As this report was undergoing final National Research Council review, a National Microgravity Research Board, with structure and purpose similar to that recommended here, was mandated in the President's "Space Policy and Commercial Space Initiative to Begin the Next Century" (The White House, February 11, 1988).

Appendix A
Charge to the Committee

1. Letter from Burton I. Edelson Requesting the Study

The NASA Office of Space Science and Applications (OSSA) asked the National Research Council's Space Applications Board to undertake a study of the NASA Microgravity Science and Applications Program, with emphasis on the potential for transfer of results to industry, and to suggest means and mechanisms for increasing its effectiveness. A copy of the letter stating this request appears on the following page.

2. The Committee's Approach, Meetings, Presenters, and Findings

At its first meeting on March 3, 1987, the committee organized to prepare its report; the Space Applications Board was subsequently briefed on the progress and plans of the committee. The second meeting was set for May 18-19, 1987, as a fact-finding session with briefings from many individuals and organizations. Representatives of different points of view and areas of expertise were chosen to address the committee. The third and fourth meetings, on July 15-16 and September 1-2, were devoted to writing of the report.

At the March 3 meeting Ms. Kathryn Schmoll, then Acting Director of the Microgravity Science and Applications Division

NASA

National Aeronautics and
Space Administration

Washington, D.C.
20546

Reply to Attn of

EN

AUG 4 1986

Dr. Arden L. Bement, Jr.
Chairman, Commission on Engineering
and Technical Systems
National Research Council
2101 Constitution Avenue, NW
Washington, DC 20418

Dear Dr. Bement:

Following up on discussions held with the Space Applications Board (SAB), I would like the SAB to undertake a study of the NASA Microgravity Science and Applications Program, with emphasis on the potential for transfer of our applications program results to industry. It would also be helpful if the Board would assess other specific aspects of the microgravity research and applications program and provide suggestions on means and mechanisms for increasing its effectiveness.

In view of the many pronouncements regarding this subject, particularly about materials processing in space, I feel that it is particularly important to begin the study as soon as possible and finish it in a reasonable amount of time, perhaps one year.

Mr. Richard Halpern, Director of the Microgravity Science and Applications Division, will be happy to work with your panel conducting the study and your staff to help with any arrangements desired.

Thank you for your responsiveness to this pressing problem. We look forward to working with the SAB.

Sincerely,

B. I. Edelson

B. I. Edelson
Associate Administrator for
Space Science and Applications

(MSAD), gave a number of suggestions regarding presenters, and she listed and described a total of nine ongoing studies of the Microgravity Science and Applications Program: (1) a NASA-sponsored study of microgravity research centers, requested through the Administrator's office, being conducted by the Microgravity Materials Science Assessment Task Force, chaired by Dr. Bonnie J. Dunbar; (2) a special study by a Task Force led by Dr. Charles Force of NASA headquarters, (3) a review of NASA microgravity research at NASA field centers by NASA Chief Scientist Dr. Frank McDonald; (4) a study of the future of materials science and engineering being carried out by the NRC's National Materials Advisory Board; (5) the Space Applications Board's Study (this study); (6) a survey of NASA extramural microgravity research by NASA's Space Applications Advisory Committee (SAAC); (7) a study of foreign competition in microgravity by the Lovelace Foundation; (8) a special review of the quality of science in microgravity flight programs at the NASA field centers, requested by the Microgravity Science and Applications Division and chaired by Dr. Robert Schrieffer; and (9) the MSAD strategic planning task force, consisting of chairmen and vice-chairmen of the six national Discipline Working Groups sponsored by the Universities Space Research Association (USRA). Ms. Schmoll stated that microgravity research may be drawing a great deal of investigative attention because (a) it is both science and applications and (b) Congress is supportive of microgravity research, so the field draws attention in the form of studies.

At its second meeting (May 18-19), the committee listened to the voices of the working community. NASA briefings were given by Astronaut Dr. Bonnie J. Dunbar and Dr. Robert Snyder of Marshall Space Flight Center. Dr. Dunbar described the role of the Mission Specialist and summarized the findings of the NASA task force she had chaired on microgravity science and applications. Dr. Snyder discussed the research program planned for the International Microgravity Laboratory (IML) missions aboard the Space Shuttle.

An international perspective was given by three speakers. Dr. Ulrich Huth described the history, current programs, and plans of the German Aerospace Research Establishment (DFVLR) with regard to microgravity research; he also provided insight into the German space program in general, including funding patterns. Mr. Robert Mitchell, of Teledyne-Brown Engineering, made a wide-ranging presentation on the capabilities and achievements of the Soviet space program, focusing on materials research and processing, both past and present. Dr. Christopher Podsiadly of 3M Company gave a presentation on industrial applications of the microgravity environment in the Japanese space program; both corporate and governmental activities and orientations were described.

The central focus of the two-day meeting was on industrial microgravity research activities. A number of corporate representatives described the activities and plans of their companies in this area and expressed their opinions (both personal and corporate) on the commercial potential of space processing and space processing research. Dr. Bruce Merrifield, of the Department of Commerce, set the keynote of the commercial focus with a talk on the economic outlook for advanced technology development in general and space technology applications in particular. Two space entrepreneurial companies were represented: Dr. Robert Citron described the SPACEHAB modules his company is seeking to develop as accessory work areas for the Shuttle, also focusing on the market and investment aspects. Mr. James Calaway, of Space Industries, Inc., and Mr. Thomas Murrin, of Westinghouse Corporation, described the Industrial Space Facility, a manned/unmanned free-flyer that they are developing jointly.

Companies actually conducting microgravity research and/or ground-based research on materials to which microgravity is potentially applicable were represented as follows:

- Dr. Glen Kiplinger, of Ortho Pharmaceuticals Division of Johnson & Johnson, described his company's activities, highlighting a continuous-flow electrophoresis project that J&J had pursued together with McDonnell Douglas.
- Dr. Robert Cooper, of Atlantic Aerospace Electronics Corporation, focused on the problem of high space transportation costs. He believes that the National Aerospace Plane will assure low-cost access to space.
- Dr. Paul McMahon described the research program of Hoechst Celanese Corporation, a firm which recently came under German ownership and was for that reason excluded from a NASA consortium for the development of materials in space.
- Dr. T.L. Nagabhushan presented the research program and objectives of Schering-Plough Co. in the biotechnology field.
- Finally, Dr. Jerry Woodall of IBM described his company's

efforts to establish a space commercialization consortium with other firms under a Joint Endeavor Agreement with NASA. The concept of a Space Ultra-high Vacuum Research Facility was featured.

In Executive Session, the committee identified some 18 separate topics, or "propositions," that had emerged from the meetings thus far. Discussion focused on certain topics: the idea of a national space facility; the use of other (current) reports on microgravity research as input to this committee's report from the standpoint of scientific/technical issues; and how best to dispel the inflated notion of manufacturing in space. Writing assignments for members were made, and the approach for writing the draft report before and during the next meeting was tentatively developed.

The third meeting of the committee (July 15-16) was a writing retreat, at which the format of the report document and the initial wording of the committee's recommendations were established. At its fourth meeting (September 1-2) the committee reviewed the written results of the previous meeting and chose the final format of the report document and the detailed wording of the recommendations. The diversity of the committee membership resulted in considerable debate throughout, and the final wording of most of the recommendations is the outcome of a consensus not always easily reached. Committee agreement on the final document was achieved by mail.

3. Background Studies and Reports

The tasks of the Committee on the Industrial Applications of the Microgravity Environment differ from those of other related committees. Some of the relevant reports produced by other committees in the past are the following.

The Committee on Scientific and Technological Aspects of Materials Processing in Space (STAMPS) was also a committee of the Space Applications Board. This committee reported in 1978, making a series of recommendations that have guided NASA's activities in this field since that time.

In a workshop conference at the Jet Propulsion Laboratory, in December 1984, the Solid State Science Committee of the NRC reviewed the program's science activities in the post-STAMPS period. The objective of the workshop meeting and resulting report was an evaluation of the program's quality. Two scientists in each of the technical fields made presentations—one overview and one specific example of a research project. In its deliberations presented as an introduction to the report, the committee made statements of its own concerning the prospects for industrial process development. These included the following:

> **CONCLUSION #3:** *"Long-range opportunities for commercialization appear to exist, but care should be taken that they are not oversold or inappropriately accelerated."*
>
> **CONCLUSION #6:** *"Opportunities for materials processing in space should not be viewed as the only justification of the program; in addition to an improved understanding of the science, a considerable return on investment is likely to result from improved technology based on research and development carried out in micro-g, but implemented in unit g."*

The NASA Advisory Council Report of the Task Force for the Commercial Use of Space (known as the "Vanderslice Report", after its chairman) was dedicated almost exclusively to questions of commercial uses of the microgravity environment. It recommended that materials research in NASA Centers for the Commercial Development of Space be undertaken on the basis of its industrial potential and that "NASA refrain from influencing research priorities based on its own concept of commercial opportunities since NASA will not make the decisions on commercialization." It further recommended that, "A rigorous priority system to determine the content of microgravity research be developed and implemented to insure that such research is usefully focused on a limited number of key areas with commercial potential."

The Microgravity Materials Science Assessment Task Force, chaired by Dr. Bonnie J. Dunbar, submitted its final report in April 1987. It was charged to:

"1. Identify essential areas of research.

2. Determine NASA's role in research, technology development, and hardware development.

3. Assess NASA's role in assisting its customers interested in the STS.

4. Develop a plan for using the Space Shuttle, Space Station, Spacelab and/or free flyers for microgravity materials processing."

The Task Force consisted primarily of NASA Division Directors, branch chiefs at Field Centers, and ad hoc commercial members. They explored a series of questions: "What is the U.S. posture in microgravity materials research? What are the major research questions and which of those appear to be of commercial interest? What is the status of the foreign programs? What are U.S. industry, government, and university concerns? Does the current flight rate allow reasonable research progress? What types of relationships between the government and industry are necessary in order to stimulate marketplace competitiveness?" The Task Force stated that "The answers to these questions cause us concern."

The introduction of this report, after pointing to examples of foreign superiority in microgravity materials science, emphasizes the commercial significance of this activity:

"The implications of this new global 'race for space' extend beyond scientific endeavors; they encompass the commercial marketplace as well. This is becoming more evident in the microgravity materials research field. The United States began its microgravity materials research in the late 1960s. During the Apollo, Skylab, and Apollo-Soyuz programs, nearly forty experiments were flown; some in conjunction with European, Japanese, and Soviet coinvestigators. These programs provided a foundation for a research field which is now nearly twenty years old."

"It is true that during the late 1970s, the credibility of the program suffered. In an effort to demonstrate the program's potential commercial 'payoff', advocates sometimes promoted unrealistic near-term rewards. When those rewards were not soon forthcoming, both economic and management support eroded; however, even as the United States retrenched its program in the late 1970s, Europe, Japan, and the USSR pressed ahead. The European program gained both focus and momentum from its involvement in developing Spacelab, while the USSR has taken advantage of a nearly continuous presence in the microgravity environment." (pg. iii)

Technical problems, such as obsolescent hardware and inflexible experiment design, are mentioned. The report concludes with 15 highly pragmatic recommendations for the improvement of access to microgravity. Some of these are cited in other appendices of this report.

The Business-Higher Education Forum addressed several problems of space industrialization in its well-known report, "Space: America's New Competitive Frontier," in which it recommended that American business play a role in bringing vision to space exploration (page 46), that NASA provide strong support for programs that include industry and especially industrial research (page 53), and that the U.S. assume an international role of cooperative leadership and not competition and secrecy (page 56).

The Space Applications Board noted, in review of early drafts of this report, that there seemed to be a lack of NASA responsiveness to the recommendations of earlier reports.

4. Report Bibliography

The following represents a sampling of documents relevant to the subject of this report, and which were utilized by the committee as background for its deliberations.

Aviation Week and Space Technology. 1984. Commercialization of Space. 120(26): 40-201.

Business-Higher Education Forum. 1986. Space: America's New Competitive Frontier. Washington, D.C.: Business-Higher Education Forum.

European Space Agency. 1985. Assessment of the Results of Fluid Science and Materials Science Experiments Conducted During the Spacelab-1 Mission. Peer review held at ESA Headquarters, October 1985, Paris, France.

Evans, L. J., Jr. 1986. Our Nation's Commercial Space Policy: An Agenda for Action. Presented to the Washington Space Business Roundtable, Washington, D.C., September 16, 1986.

Johnson, K. P. 1986. Perspectives on Material Processing in Space. Paper presented at NAE Symposium on Explorations in Space Policy, Washington, D.C., June 1986.

Johnson, N. L. 1987. The Soviet Year in Space, 1986. Colorado Springs, CO: Teledyne Brown Engineering.

NASA. 1987. Microgravity Materials Science Assessment Task Force – Final Report (B. Dunbar, Chair). Washington: National Aeronautics and Space Administration.

NASA. 1987. NASA Press Release of June 17, 1987: NASA Post-Challenger Commercial Activity Policies Adopted (Secondary STS Payloads, ELVs Policy, Commercialization Policy, JEAs, Responsibility for Programs Utilizing the Microgravity Environment).

NASA Advisory Council. 1985. Report of the Task Force for the Commercial Use of Space (T. Vanderslice, Chair). Washington, D.C.: National Aeronautics and Space Administration.

NASA Advisory Council. 1987. Study of the Issues of a Mixed Fleet (Report of a Task Force). Washington, D.C.: National Aeronautics and Space Administration.

NASA Marshall Space Flight Center. 1986. Mission Requirements on Facilities/Instruments/Experiments for Space Transportation Systems (STS) Attached Payloads, JA-447, Rev. A, (CCBD 200-86-0016) September 1986.

NASA Marshall Space Flight Center. 1986. Payload Mission Manager Interface and Safety Verification Requirements for Instruments, Facilities, MPE, and ECE on Space Transportation System (STS) Spacelab Payload Missions, JA-061, Rev. B, (CCBD 200-86-0026) December 1986.

NASA Office of Space Science and Applications, Earth Science and Applications Division. 1987. Program and Plans for FY 1987, 1988, 1989. Washington: National Aeronautics and Space Administration.

NASA Office of Space Science and Applications, Materials Science and Applications Division. 1986. Microgravity: A New Tool for Basic and Applied Research in Space (EP-212). Washington: National Aeronautics and Space Administration.

National Research Council, Committee on Scientific and Technological Aspects of Materials Processing in Space (STAMPS). 1978. Washington, D.C.: National Academy of Sciences.

National Research Council, Solid State Sciences Committee. 1986. Microgravity Science and Applications: Report of a Workshop, December 1984. Washington, D.C.: National Academy Press.

U.S. Congress, 1985. International Office of Technology Assessment. Cooperation and Competition in Civilian Space Activities (OTA-ISC-239). Chapter 8, "Materials Processing in Space". Washington, D.C.: U.S. Government Printing Office.

Wang, T. G. 1986. Commercial Task Review. Papers prepared for NASA Commercialization of Space Review Task Force, December 18, 1986.

Appendix B
NASA Leadership in Microgravity Research

1. Recommendations

"NASA should take a leadership role in ensuring that the valuable microgravity environment is used wisely, aggressively, and fairly in pursuit of basic science and its application to the nation's interests."

"In view of present resource and knowledge limitations, we recommend that NASA focus its current microgravity progam on basic materials science, processing research, and in-space processing technology, rather than on manufacturing."

2. Microgravity as a New Variable

Whenever density differences are present on a scale greater than that of a single molecule, the factor g (gravity) plays a significant role in the equations of motion used in physics and chemistry and in the dimensionless groups used in fluid engineering. In such cases, inertial acceleration is the same kind of variable as temperature, pressure, electric field, etc.

The NASA Advisory Council Task Force for the Commercial Use of Space stated that "use of the microgravity environment in space to improve and/or develop a wide range of materials and material processes, including earth-bound processes, may have the largest commercial potential of any space activity." It also pointed out that "the available scientific microgravity data base is inadequate to attract significant private sector investment in the development of commercial applications."

The impact of microgravity studies on industrial processing will be pronounced. To attempt to predict or specify in any detail the beneficial effects of near-zero gravity conditions is to ignore the fact that predictions on the impact of high vacuum, high temperatures, and pressures on all materials technologies have invariably been severely underestimated. One can cite high-performance metal structures, high-temperature ceramic technologies, and solid state electronics as examples.

Microgravity conditions should be approached as other important parameters have been in the past, i.e., systematically and with foresight. The study of the effects of microgravity on fundamental processing parameters (e.g., heat and mass transport) is a necessary starting point. It will reveal new interactive modes of processing parameters which will have scientific importance and will provide industry with new means for pursuing the development of new and improved materials and processes, and thus of new technologies.

3. Microgravity Materials Science Activities

3.1 Research

Materials and processes research constitutes nearly 100% of microgravity research today, including that supported by the corporate sector. This activity is sponsored by NASA primarily through two of its divisions, the Commercial Development Division of the Office of Commercial Programs ("Code C," formerly "Code I") and the Microgravity Science and Applications Division of the Office of Space Science and Applications ("Code E"). Although these two Divisions have somewhat different charters, their program contents are similar.

A. Office of Commercial Programs

This Office has initiated a variety of efforts to stimulate industrial interest. Hardware projects envisaging future needs have been funded at about $8 million this year. Centers for the Commercial

Development of Space (CCDSs) have been funded for materials processing. These centers are assured of five years of funding by NASA. At the end of five years they are expected to be self-sufficient and drawing their support from industry. There have been six centers selected thus far for materials processing. These are:

Clarkson University - Crystal Growth
University of Houston - Molecular Beam Epitaxy
Battelle Columbus Lab - Multiphase Materials
University of Alabama, Birmingham - Macromolecular Crystallography
University of Alabama, Huntsville - Materials Processing
Vanderbilt University - Metallurgical Processing

A total of about $6 million will be paid to these organizations in FY '87 and FY '88. Seven additional centers were funded in 1987, some of which include microgravity research components.

OCP has also developed a variety of standard agreements to match the needs of industry. These are as follows:

1. **Memorandum of Understanding (MOU)** - This agreement is usually a precursor to a Joint Endeavor Agreement (JEA-see item 6 below). It essentially expresses NASA's interest in the concept and is typically limited to an exchange of information. An MOU is useful to the firm proposing this concept, in that it assists the firm in raising funds to pursue the idea further.

2. **Technical Exchange Agreement (TEA)** - The TEA is aimed at those firms that are not ready to commit to a flight experiment and wish to "test the water" at minimal expense. NASA provides access to its ground facilities and aircraft as well as technical information. NASA holds the first publication rights for NASA-developed data, but no rights are retained by NASA on data developed by the private entity.

3. **Industrial Guest Investigator Agreement (IGIA)** - This provides a means of achieving a NASA/industry collaboration on research in scientific areas of mutual interest. The company funds a researcher to work with a principal investigator on NASA-sponsored experiments.

4. **Space System Development Agreement (SSDA)** - This agreement is reserved for efforts that are perceived to be of national or social significance. It may provide launch with special concessions to the company, such as exclusivity and/or deferred payment.

5. **Memorandum of Agreement (MOA)** - This an omnibus type of agreement that can be tailored to the situation. It can provide technical assistance, launch facilities, etc. In any case, NASA is to be reimbursed for costs associated with this agreement.

6. **Joint Endeavor Agreement (JEA)** - This agreement is the ultimate objective. It is initiated when a private entity is willing to invest in hardware or experiment developments and commit to commercialize economically viable results. NASA provides Shuttle flights and standard services. Optional services are paid by the entity. Although there is no exchange of funds, every attempt is made to minimize the financial and technical risk to the entrepreneurial effort.

OCP's budget for commercial programs is described in Table B-1.

TABLE B-1 Funding Profile for NASA Office of Commercial Programs, Commercial Use of Space (Dollars in Millions)

	FY '86	FY '87
Commercial Applications R&D	12.94	22.63
Centers for the Commercial Development of Space	(7.43)	(11.00)
Commercial R&D Enhancements	(5.51)	(11.13)
Integration	----	(0.50)
Commercial Development Support	1.85	3.00
Studies	(0.68)	(1.23)
Support Services	(1.17)	(1.77)
Commercial R&D Enhancement Maintenance	----	----
Total Commercial Use	14.79	25.63

B. Microgravity Science and Applications Division

The Microgravity Program of this division is made up of six distinct disciplines:

- Metals and Alloys
- Glasses and Ceramics
- Electronic Materials
- Combustion Science
- Biotechnology
- Fluid Dynamics and Transport Phenomena

Sponsored research efforts are conducted at approximately 50 universities, 10 industrial organizations, 3 non-profit organizations, the National Bureau of Standards, 4 NASA field centers, and the Jet Propulsion Laboratory, as well as at the NASA Centers cf Excellence.

There are two elements to the program: flight research and ground-based research. Flight research includes apparatus development, principal investigator support, and data analysis activity directly related to flights aboard the Space Transportation System (STS). Three different flight modes are available: the middeck area, the cargo bay on specially-designed support structures, and the Spacelab pressurized module and pallets. The flight program makes use of all these modes. Fourteen (14) flight experiments were flown in 1985, using nine pieces of hardware. This number is less than half the experiments planned, and therefore only limited results were achieved in some research areas. By contrast, in 1985, ESA flew 41 experiments, using 10 pieces of hardware.

The ground-based research program consists of laboratory research at principal investigators' home institutions and the use of NASA ground-based facilities, including drop tubes, drop towers, and aircraft. Use of these ground-based facilities establishes the necessary criteria and relevance to the microgravity environment prior to commitment to space flight. The Centers of Excellence and Microgravity Materials Science Lab are also part of the ground-based research program.

In 1985, the number of research proposals received doubled over the prior year, indicating the increase in awareness of, and interest in, the program. The number of papers by NASA MSAD-sponsored investigators in referenced journals increases yearly.

The FY 1987 budget of MSAD was $34 million. This was supplemented with $12.5 million for "advanced technology development"; the FY 1988 budget is expected to be more than double the FY 1987 budget (see also Appendix F).

3.2 In Situ Processing

In order to provide facilities in space such as structures, electronic and mechanical equipment, and an appropriate environment for people and equipment, conducting and understanding a variety of microgravity processes is essential and must be an object of NASA's processing program. Examples include the joining of metals in space and lubricating and tribology in microgravity and high vacuum. Considerable research has been carried out in some of these areas, but if the U.S. commitment to longer-term and larger-scale space activities is to be successful, a sustained NASA commitment to such materials studies is essential. The microgravity processes to be understood and managed are usually not the same as those of interest for understanding ground-based processes or for establishing a knowledge base for possible future manufacturing. The choice of areas for investigation can be prioritized by an analysis of future NASA projects. Joint activities with the industrial vehicle and space equipment supplier community will be key to success. This is an area where more industrial involvement is appropriate now, and NASA is urged to devise mechanisms to enhance involvement.

3.3 Space Manufacturing

One product manufactured in space, is, in fact, being sold—namely, monodisperse latex microspheres manufactured on Shuttle flight STS-3 and subsequent Shuttle flights. This product is sold on the high-quality standards market by the National Bureau of Standards, which has served a small but significant number of satisfied customers. The product was manufactured by university-based scientists totally funded by NASA.

Prior to the Challenger accident, NASA and some of its contractors promoted the notion that space manufacturing was imminent. Microgravity was to have been the unique characteristic of the space environment that private firms, in cooperation with NASA, would exploit to manufacture goods in space to be sold on Earth. In 1984, drugs, materials to make semiconductors, and new glasses were estimated to account for as much as 40 billion dollars a year in gross sales by the turn of the century. One article cites a Center for Space Policy estimate of $41.5 billion annual sales for these three product groups and a Rockwell International estimate for the same group of products of $30 billion.[3] These estimates were predicated on the assumption of widespread corporate interest in space manufacturing and a rapid accumulation of scientific and technical knowledge about the gravity parameter gained by frequent and low cost access to space. As neither low-cost nor frequent access to space was a realistic prospect at the time, such an optimistic outlook for space manufacturing was more justified as a public relations exercise than as a realistic market forecast.

While space manufacturing was not the sole or even the dominant goal of the NASA microgravity effort in the mid-1980s, it was the most visible and publicized. The visibility afforded several demonstration projects raised expectations of immediate economic benefits. As difficulties were encountered prior to the Challenger accident—for example, fewer flight opportunities than expected and higher shuttle prices than forecasted for the late 1980s—the prospects for space manufacturing began to diminish. In the case of the most publicized demonstration project, the McDonnell Douglas/Johnson & Johnson joint venture, the medical and commercial interest in the material under investigation (erythropoietin) led to intense and ultimately successful efforts to find an earth-based alternative to purification in microgravity.

4. Categories of Microgravity Research

The six categories of microgravity research recognized by MSAD were introduced above (See 3.1-B). The broad and general goals of each discipline can be stated as follows:

1. **Metals and Alloys:** Investigate the formation of alloys of metals having very different densities; study float zone refining; assess differences in the welding process in microgravity.
2. **Glasses and Ceramics:** Form new and more uniform crystals and glasses of dielectric materials through study of the gravity dependent aspects of the solidification process.
3. **Electronic Materials:** Apply microgravity methods to the study of the process of solidification of highly crystalline semiconducting and transducing materials such as GaAs, HgCdTe

[3] Unique Products, New Technology Spawn Space Business. Aviation Week and Space Technology, 1984, 120(26):4-9.

and a variety of III-V semiconductors; manufacture these materials in microgravity.

4. **Combustion Science:** Study the structure of flames and gaseous fuel transport in the absence of convection, define fire safety requirements in low gravity.

5. **Biotechnology:** Perfect and scale up separation processes; study the production of high quality crystals and matrices of macromolecules, evaluate cellular and biological responses;

6. **Fluid Dynamics and Transport Phenomena:** Predict and evaluate the effects of forces normally masked by gravity; study the processes of production of polymers and composites; serve specific scientific needs of the other five disciplines.

While polymer science merits attention as a separate discipline, according to the MSAD its goals are currently embodied within the framework of each of the above disciplines.

Appendix C
Involvement of U.S. Industry

1. Recommendation

"Given the scarcity of near-term profitable ventures requiring the microgravity environment, and the desirability of having industry and government working together in this field (including research interactions between NASA and industries), we recommend that the U.S. Government and NASA encourage firms to participate in microgravity research and technology development (either alone or in the form of consortia, such as those sponsored by the Centers for Commercial Development of Space) by actively supporting such industrial research and by reducing the barriers to that participation."

2. The Space Act

The National Aeronautics and Space Act of 1958 mandates NASA to pursue the expansion of human knowledge of phenomena in the atmosphere and space and the preservation of U.S. leadership in the application of space science and technology for peaceful purposes. (Public Law 85-568, 85th Congress, Section 102.)

In 1985 this Act was amended to create the NASA Office of Commercial Programs, which absorbed the former Office of Technology

Utilization as a Division and created the Commercial Development Division. The former facilitates transfer of technology developed for the space program to the civilian commercial sector, while the latter involves U.S. corporations in space research through specific types of agreements (described in Appendix B).

3. Formal Agreements Between Companies and NASA

There are several mechanisms whereby corporations can become partners with NASA to effect microgravity (and other space) research projects. These agreements are continually undergoing changes in name and character. A concise characterization of the types of contracts available currently is given in Appendix B, section 3.1-A. Among these, the "Joint Endeavor Agreement" (JEA) is one of the most desirable contracts; no cash changes hands and NASA provides free launches for the company, which in turn provides NASA with access to its flight hardware, a royalty-free license to any resulting technology, or similar participation in the value and/or equity produced by the joint activity.

4. Summary of Major Industry-NASA Microgravity Projects

A major goal in NASA's microgravity program has been to enlist the support of U.S. industry. The United States began its microgravity materials research in the late 1960s with the cooperation of a limited number of U.S. industrial concerns interested in the development of equipment or in the processing of materials per se. During the 1970s, the credibility of the program began to falter, however, as advocates promised unrealistic rewards (see Dunbar Report).

Nevertheless, as cited, for example, in the 16 Centers for the Commercial Development of Space operative in December 1987, under the auspices of the NASA Office of Commercial Programs, six are dedicated to materials processing in the microgravity environment. The stated objective of this program continues to be to accelerate applications and use of space technology by the private sector. As of January 1987, 58 U.S. corporations were said to be participating to some degree in the activities of the centers, although it is not known how many of these participations are in direct microgravity studies. It is the impression of the committee that the cost to these corporations of participation has been low and the risks taken by them have been minimal. Industry will participate for long-term strategic reasons if the risks and barriers are sufficiently low.

Current corporate microgravity research activities fall into three broad categories: (1) *service providers*, such as Rockwell, TRW, Space Industries Inc., and SPACEHAB, who build hardware and potentially orbiting laboratories; (2) *companies that transfer their corporate R&D to the space environment*, such as 3M, John Deere, Exxon, and EG&G, who grow crystals and form solids for research; and (3) *space manufacturers*, such as McDonnell Douglas and Microgravity Research Associates, who plan production of high-value products (pharmaceuticals and electronic materials, respectively).

However, at present U.S. industry perceives little near-term incentive for manufacturing in space. Testimony given to the committee by representatives of pharmaceutical and electronic materials corporations that participated in early experiments aimed directly at commercialization supports the conclusion that early enthusiasm for commercial applications has given way to a more realistic assessment, and that there is little current interest in direct pursuit of applications. In some cases — e.g., purification of rare proteins — the value of microgravity separation has been supplanted by recombinant DNA methodologies which made formerly rare proteins readily available.

In spite of the scarcity of near-term profitable ventures requiring the microgravity environment, NASA should not abandon its goal of involving industry in a national research program.

5. Time to Formation of Joint Endeavor Agreements

To date, a rather small number of Joint Endeavor Agreements between NASA and companies have been signed. The first few contracts were signed only after an average of 18 months of negotiations. Additionally, during the STS standdown there has been a "hold" on the approval of JEAs while decisions concerning alternative types of contracts were being made and the future of the JEA was being established (see Dunbar Report). This timing is considered a deterrent to businessmen, who have an aversion to restrictions and an inherent interest in timeliness.

Appendix D
International Cooperation

1. Recommendation

"We recommend that the U.S. government enhance the collaboration between U.S. and foreign microgravity scientists to the greatest extent consistent with U.S. interests. NASA could facilitate this collaboration by the following means: (1) allow foreign-owned companies from friendly nations to participate in NASA microgravity research consortia, and (2) create a Task Force-type group to explore mechanisms for interacting internationally to maximize scientific return while protecting U.S. interests."

2. NASA Restrictions on Foreign Commercial Participation: Language of Contracts; the Hoechst/Celanese Case

While NASA encourages, in spirit, scientist-to-scientist collaboration in microgravity research, and foreign scientists can become STS investigators much more cheaply if they have American collaborators, the participation of foreign-owned companies in NASA-sponsored Centers for the Commercial Development of Space is strictly forbidden. As international buy-outs continue an increasing number of U.S.-based companies that employ American workers

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are becoming ineligible as both beneficiaries and benefactors of the CCDS program. For example, a representative of Celanese Corporation who was invited to testify before the committee found it necessary to tell the committee that, once his firm had become Hoechst-Celanese (the world's third largest chemical company), he had to absent his company, and its interests in microgravity research, from the CCDS of which Celanese had been a contributing member.

3. European Space Agency

STS flights of SL-1 and D-1 Spacelab missions were, in the main, ESA and German missions, respectively. During these two missions, European scientists flew as many microgravity experiments as did their American counterparts did on 21 Shuttle flights (Dunbar Report, p. 10).

4. European National Programs: Germany, France, Italy

The German Aerospace Agency, DFVLR, works very closely with the NASA Office of Space Flight and succeeded in planning and funding two complete Spacelab missions of its own. The first, D-1, contained the most extensive array of microgravity research experiments ever flown, while the second, D-2, will presumably fly in 1989 and include, like its predecessor, a number of American experiments. Microgravity research has a high priority in the DFVLR program. The French National Center for Space Studies (CNES), which places considerable emphasis on astronomy and earth observation, is building an aggressive program in microgravity research. Aeritalia is the Italian national agency for space research.

European agencies and corporations are responsive to INTOSPACE, Europe's space commercialization corporation, for commercialization activities. As with NASA's OCP, INTOSPACE has initiated a flight hardware development enterprise, but it is more aggressive and productive than its U.S. counterpart — to the extent that Americans might consider leasing INTOSPACE hardware.

5. Japan: Research Program History and Plans

Japan's approach to microgravity research resembles the nation's corporate culture in general. The National Aeronautics and Space Development Agency (NASDA) is a development agency, while "trading companies" are responsible for organizing consortia of manufacturers (1 to 70 per consortium), and do the actual commercial planning and assignment of space experiment development among their member companies. The Japanese Space Utilization Promotion Agency (JSUP) promotes and facilitates corporate participation in specific space research experiments. For example, Hitachi is building electrophoresis equipment, and Fujitsu is developing a Getaway Special (GAS) canister for protein crystal growth.

6. USSR: Program History, Launch Data

As the Soviet Union is also a successful spacefaring nation, the use of collaboration in space as a tool of diplomacy should not be limited to our Western allies. The Soviet Union launched nearly 200 times during the last two calendar years, and the People's Republic of China in recent months completed their first five-day microgravity mission in which some five different materials were solidified. There is eagerness to cooperate with the United States on the part of both of these potential partners, and, at least in case of the Soviet Union, it is now reasonable to surmise that technology transfer can occur in two ways. The current situation permits scientist-to-scientist collaboration in space research in non-sensitive areas, such as space physiology and planetology, but there is very little collaborative activity sanctioned by the State Department and no official encouragement for U.S.-Soviet and U.S.-Sino collaboration. In the same sense that sharing technology builds global markets in the West, it should be assumed that sharing basic science with the socialist countries will similarly build future markets. In addition, launch opportunities are quite different in East and West, and it is fully consistent with the American desire for a variety of means of access to space and low gravity to include flights on the vehicles of other space-faring nations Glavkosmos, the Soviet agency charged with commercializing the Soviet space system and marketing space research opportunities to the western world, invites paid participation by parties from all over the world. The committee speaks to NASA, the Department of State, and the Administration as a whole on this issue.

While one of the U.S.'s most authoritative documents of Soviet space activities, "The Soviet Year in Space," published annually by Teledyne Brown Engineering (Johnson, 1986) indicates that the USSR launches more than 80 rockets destined for earth orbit or beyond each year, it has very little to say about Soviet achievements in microgravity research. From the widely circulated books and reports by V.S. Avduyevsky and by Dr. Lea Regel, however, we know that more than 1700 microgravity experiments have been performed by the Soviets (see following references). Some of these have been rather sophisticated, using, for example, the "Korund" furnace with 12 zones and a solution crystal growth system with holographic monitoring. The budget expenditures for this level of effort are difficult to identify and even more difficult to compare, as the salaries of the 25 Ph.D.'s who work full-time at the Institute for Space Research, in Moscow, could be as low as 1/5 that of their western counterparts.

7. China: Recent Experiments

The Great Wall Corporation produces the Long March II rocket, which is capable of lofting substantial payloads (e.g. communications satellites) to orbit. The first Chinese microgravity flight occurred August 1-5, 1987, and was reported briefly in the United States by Prof. Xi-Shen Chen of the Academia Sinica, Institute of Physics, Beijing. About five substances were solidified (mainly electronic materials) and retrieved in a recoverable capsule (utilizing a bamboo ablation shield!) after five days in orbit.

8. Cooperative Mechanisms

A considerable range of cooperative agreements has been arranged, and agreements are being negotiated between the United States and other nations. The United States has signed agreements with Canada, Japan, and ESA to cooperate in the design phase (phase B) of NASA's International Space Station program. Each country will assume its own cost for this and subsequent phases.

9. References

Avduyevsky, V. S. 1985. Manufacturing in Space: Processing Problems and Advances. Moscow: Mir Publishers.

Johnson, N. L. 1987. The Soviet Year in Space, 1986. Colorado Springs, CO: Teledyne Brown Engineering.

NASA. 1987. Microgravity Materials Science Assessment Task Force - Final Report (B. Dunbar, Chair). Washington: National Aeronautics and Space Administration.

Regel', L. L. 1986. Analysis of New Results in Space Materials Science. Moscow: Academy of Sciences of the USSR Space Research Institute.

U.S. Congress. 1985. International Office of Technology Assessment. Cooperation and Competition in Civilian Space Activities (OTA-ISC-239). Chapter 8, "Materials Processing in Space." Washington, D.C.: U.S. Government Printing Office.

Appendix E
Access to Microgravity Research Opportunities

1. Recommendation

"We recommend that NASA maximize access to microgravity by fully utilizing the widest possible range of microgravity facilities. In addition, we strongly recommend that research efforts focus on the development of improved ways of pursuing remote, unmanned microgravity research (i.e., research methodologies, sensors, effectors, etc.). Over time, the microgravity research community should attempt to reduce the percentage of experiments that require continuous manned tending, and those microgravity experiments that must be manned should be considered by NASA as Primary Payloads, to the extent possible."

2. List of Major Microgravity Facilities

The following items are currently considered available as American microgravity hardware to be used on the Space Shuttle, including Spacelab:

- General Purpose Rocket Furnace
- Automated Directional Solidification Furnace
- Advanced Automated Directional Solidification Furnace

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- Static Column Electrophoretic Separator
- Continuous Flow Electrophoresis System
- Isoelectric Focusing Experiment
- Single Axis Acoustic Levitator
- Three Axis Acoustic Levitator
- Acoustic Containerless Experiment System
- Electromagnetic Levitator Furnace
- Fluids Experiment System
- Fluid Experiment Apparatus
- Vapor Crystal Growth System
- Monodisperse Latex Reactor System
- Solute Diffusion Apparatus

3. List of Microgravity Levels and Vehicles

Table E-1 indicates the relative acceleration and the duration of low g in several facilities.

TABLE E-1 Comparison of Microgravity Facilities

Facility	Approximate Accelerat.(g)	Microgravity Duration	Frequency of Reuse
Drop Tower	10^{-5}	2 sec.	Several/day
Drop Tube	10^{-6}	6 sec.	2x/day
KC-135 Flight	10^{-2}	~20 sec.	Monthly
Rocket Flight	10^{-4}	~ 6 min.	None
Secondary Payload	10^{-4}-10^{-5}	~ 7 days	Biannual after 1989
Primary Payload	10^{-4}-10^{-5}	~ 7 days	1990 & 1991 (D-2, J-1, and maybe US-1)
Space Station	10^{-3}-10^{-5}	~ Months	~ 1994
Indust.Space Fac.	10^{-6}	~ Months	Planning Stage

4. The Mixed Fleet Concept

During the early months after the Challenger accident, several official groups made their voices heard concerning the need for unmanned spacecraft to more efficiently conduct scientific missions and to diversify the nation's access to space. Restarting the production lines for existing expendable launch vehicles (ELVs) such as Titan and Delta was recommended, and studies of free-flying orbiters for microgravity and life sciences research were stepped up. Even the complete abandonment of manned space flight was considered in some circles. NASA life scientists are currently taking advantage of Soviet unmanned flight opportunities, and they are anticipating future U.S. recoverable-vehicle experiments. Non-orbiting facilities, such as the first four items in Table E-1, are being used increasingly—with the exception of sub-orbital rocket flights, which have not yet returned to the U.S. "fleet" but are used routinely by ESA ("Texus") and in the USSR ("Mir-2").

Thus, a successful "mixed fleet" consists of microgravity facilities aboard KC-135 aircraft, sounding rockets, unmanned recoverable and non-recoverable orbiters, man-tended industrial space facilities, and fully-manned craft, such as the Shuttle and Space Station. Specific experiment goals can be optimally met by a wise matching of each microgravity experiment to the appropriate facility in the mixed fleet. (See Appendix F.)

5. Planned Space Station Microgravity Facilities

A number of modular experiment hardware units in standard racks have been planned for the International Space Station:

1. Modular Containerless Processing Facility (MCPF)
2. Modular Multizone Furnace Facility (MMFF)
3. Biotechnology Facility (BF)
4. Advanced Protein Crystal Growth Facility (APCGF)
5. Fluid Physics/Dynamics Facility (FPDF)
6. Modular Combustion Facility (MCF)

6. Microgravity Research and Access to Space

6.1 Needs

Progress in space science and applications depends upon space flight. Microgravity materials research is no exception. Materials experimentation began during the Apollo program and continued on the Skylab orbiting space station. Several Space Shuttle flights included major materials experiments, most significantly three Spacelab flights on which scientist/astronauts were able to work directly with their experiments in a shirt-sleeve environment. Unmanned experiments have been flown on smaller sounding rockets, and these could be flown on larger retrievable space platforms (such as the Long Duration Exposure Facility currently stranded in orbit as a consequence of the Shuttle standdown) or as attached payloads to other primary missions launched from the Shuttle or conventional rockets. The Space Station program anticipates extensive materials experimentation in its lab modules and upon a co-orbiting platform periodically visited by the station crew.

In the wake of the Challenger accident the opportunities for microgravity experimentation between 1988 and 1996 are very limited. The "Dunbar Report" found the paucity of flight opportunities to be the driving force in the current environment; making more difficult choices among competing disciplines, increasing the tension between a "pure" scientific research agenda and one more oriented towards industries, and accentuating strains within the NASA effort between the Office of Space Science and Applications program (MSAD) and the Office of Commercial Programs efforts. (NASA, 1987). Moreover, without additional flight time it is unlikely that U.S. materials research will have progressed sufficiently to make prompt productive use of the Space Station. The committee views this situation with concern and sees a need to ensure that:

- Microgravity payloads continue to receive high priority as the Shuttle schedule evolves;
- Technologies that support unmanned materials experimentation be developed; and
- Additional access to space for materials processing be supported in the pre-Space Station period in the form of unmanned or man-tended spacecraft.

6.2 Current Status

Prior to the Challenger accident the Space Shuttle was to have flown a series of microgravity payloads, from the highly visible Spacelab flights to major experiments attached to instrument pallets in the Shuttle cargo bay, to a number of secondary payloads in the middeck or cargo bay. Numerous major microgr[illegible]vity payloads were shown in Table I of the NASA Space Tra[illegible]a System, Space Shuttle Payload Flight Assignments, No[illegible]5. Current plans have pushed these flights back into the 19[illegible]xperim[illegible] be flown as secondary payloads also ha[illegible]d bac[illegible] sured by weight, NASA estimates tha[illegible] der[illegible] secondary payloads can be satisfied. [illegible]eriments [illegible] dominate the load that is carried, however.

6.3 Improving Access to Space

NASA representatives indicated to the committee that materials research is perhaps the most important near-term use of the Space Station, which will be operational in the mid-1990s. According to some authoritative estimates, the national investment in the Space Station could exceed 30 billion 1988 dollars before the end of the century. Thus, support for microgravity research between now and the beginning of Space Station operation is critical if the station is to be effectively used in its early years of operation. Effective microgravity research will be limited by flight opportunities if increased provision for such opportunities is not made.

The issue extends beyond the priority on the Shuttle granted to microgravity payloads, primary or secondary. The committee adds its support to the many elements of the space technology and science community encouraging NASA to use expendable launch vehicles where possible to fly payloads suitable to those vehicles. In this way more flight opportunities will [illegible]le to those payloads requiring the unique attributes of the [illegible]

A number of options to in[illegible] space f[illegible]vailable for microgravity research s[illegible]ed. T[illegible]d include unmanned as well as man[illegible] and co[illegible]require significant investments not currently [illegible] in the NASA budget plan. Among the options examined by the committee were extending the orbiting time of the shuttle to permit lo[illegible]ration experiments, investment in technologies to fly unman[illegible]aterials experiments, and an interim man-tended orbiting platform to be made available sometime in the early 1990s.

7. Summary of Primary/Sec[illegible]les & Distinctions

Primary Payload refers to ex[illegible]nts, "carriers", and satellites that are manifested for a spec[illegible]ght in a specific location in the Shuttle payload bay and [illegible]act on normal operation of the orbiter." Satellites to be l[illegible]nd the Spacelab module are examples of Primary Payloads. *Secondary Payload* refers typically to experiments that occupy space in the Shuttle mid-deck or a mid-deck locker "with no imp[illegible]orbiter operation." A real-time priority system establishes [illegible]her or not a particular Secondary Payload will actually fly, although Secondary Payloads are normally manifested at the same time as Primary Payloads. For example, a fluids experiment manifested for flight in a mid-deck locker could be removed from the orbiter prior to flight based on a priority decision to add a payload specialist. *Payload of Opportunity* refers to loads manifested without priority if they happen to fit the mass and center-of-gravity pattern of a particular flight. Examples are Get Away Special canisters and Hitchhiker modules. Payloads of Opportunity are loaded into the orbiter 4-6 weeks prior to launch.

8. References

NASA. 1987. Commercialization of Space Review. Report of the Commercialization of Space Review Task Force (C. Force, Chair). Washington, D.C.: National Aeronautics and Space Administration.

NASA. 1987. Microgravity Materials Science Assessment Task Force - Final Report (B. Dunbar, Chair). Washington: National Aeronautics and Space Administration.

NASA. 1985. Marshall Space Flight Center, Microgravity Science and Applications Division, Program Development Directorate, Commerciaiization of Materials Processing in Space Group. Microgravity Science and Applications: Experimental Apparatus and Facilities. Huntsville, AL: NASA MSFC.

Appendix F
Management and Use of U.S. Microgravity Resources

1. Recommendation

"Because of the limited access to this unique research environment, and because of the range of interested parties, we recommend that the federal government establish a senior advisory board composed of representatives of industry, academe, and interested government agencies. The mission of this board would be to maximize multi-sectoral participation in the civilian microgravity program, and to facilitate the implementation of the foregoing recommendations of this committee. Such a board could be housed in an existing policy office of the Federal Administration, with NASA as its leading agency."[4]

[4] As this report was undergoing final National Research Council review, a National Microgravity Research Board, with structure and purpose similar to that recommended here, was mandated in the President's "Space Policy and Commercial Space Initiative to Begin the Next Century" (The White House, February 11, 1988).

2. Shuttle and Spacelab Facilities for Microgravity Research

A list of Shuttle and Spacelab hardware made by or for U.S. users was given in Appendix E, section 2. Some of these were adapted from previous missions, such as Apollo or sounding rockets, and some were designed for experiments already performed and not likely to be repeated. The remaining items constitute a list that is short by international standards. These facilities are akin to a "beam line" at a multi-user national accelerator facility; they are available for use by individual investigators, but they differ from a typical beam line in not having users' committees. Nevertheless, they are similar in their value, monetarily and as a national resource. Physically, these facilities range from a mid-deck locker unit (about 40 × 40 *times* 25 cm) to a Spacelab double rack (about 65 × 40 × 240 cm) in size. Power requirements vary from a few watts to a few kW (peak). Arrangements are now underway to develop a capability for accommodating mid-deck locker units and higher temperature (>2000 deg C) furnaces. The Dunbar Report suggests that future microgravity hardware planning include the development of multi-user facilities, special-purpose facilities that can be modified to do the experiments of other investigators well, and modular equipment designed for rapid interchange of parts to successfully accommodate a range of anticipated experiments.

3. Expendable Launch Vehicles for Microgravity Missions

Many microgravity experiments require the gentle launch and recovery accelerations of the Space Shuttle, or human tending, or both; but there are some experiment types that can be performed in rugged, remotely controlled and monitored equipment suitable for launching on Titan or Delta rockets. The Life Sciences Division of OSSA intends to take advantages of these possibilities and is studying a recoverable orbital system "Lifesat." The Martin-Marietta and McDonnell Douglas companies, respectively, are prepared to produce these launch vehicles, and the "Scout" rocket is also capable of lifting a few hundred pounds to low-earth orbit.

4. Ground-based and Non-orbital Microgravity Research Facilities

These consist of drop towers (2 sec., at NASA Lewis Research Center), drop tubes (5 sec., at NASA Lewis and Marshall Centers), aircraft equipped for high-altitude parabolic flight (20 sec., in Johnson Space Center KC-135 and Lewis Lear Jet), and suborbital sounding rocket flights (7 min., in U.S.-Canada Black Brandt, Germany-Sweden Texus, and USSR Mir-2). All of the U.S. systems are considered national user facilities.

5. Organizing an Experiment Through NASA

The following pages document, in outline form, the procedures followed by a typical commercial user who performs an experiment on the Space Shuttle middeck.

5.1 Flow Chart for Commercial Payloads

Table F-1 summarizes the various steps involved in flying a materials processing experiment on the Space Shuttle system. The complexity associated at each specific step in the process, the paperwork required, and the logistics of operating from coast to coast in the United States is not reflected in the table. Using a NASA-supplied Mission Manager after Step 3 reduces the work required on the part of the user but increases the paperwork and introduces various contract personnel on the NASA side.

5.2 Definitions of Terms

Code E – Office of Space Science and Applications
Code C – Office of Commercial Programs
Code M – Office of Space Flight
JSC – Johnson Space Center, Houston, Texas
KSC – Kennedy Space Center, Cape Canaveral, Florida
Dryden – Dryden, Edwards AFB, California
MSFC – Marshall Space Flight Center, Huntsville, Alabama
LeRC – Lewis Research Center, Cleveland, Ohio

Joint Endeavor Agreement (JEA) - Pursuant to the National Aeronautics and Space Act of 1958 [Section 102(c)] and NASA's Guidelines Regarding Joint Endeavors with U.S. Domestic Concerns in Materials Processing in Space, published August 14, 1979, NASA desires to enter into joint endeavors with U.S. industrial concerns. See Appendix B, section 3.1-A, for definition.

STS-100 Form - This form (now designated Form 1628) is an authorization document that certifies the validity of the flight requirements presented by the user and implies the commitment of NASA resources to support the implementation of a flight opportunity. Acceptance

TABLE F-1 Steps to Flight of Materials Processing Experiment Aboard STS[5]

Requirement	NASA Contact
1. Agreement/Contract Joint Endeavor Agreement (JEA)	Code C, Code E Washington, D.C.
2. Science Collaboration	Code E Washington, D.C. & Field Centers (MSFC; LeRC)
3. Flight Manifest STS-100 Form	Code M, Washington, D.C.
4. Payload Integration Plan (PIP) Preliminary Design Review (PDR) Critical Design Review (CDR) Baseline PIP Annexes (1-9)	Code M, JSC
5. Flight Safety Reviews 0 - NASA Supplies Rules 1 - Response to Rules 2 - Exhaustive Review 3 - Final	Code M, JSC
6. Launch Site Support Plan (LSSP) Annex 8 to PIP Ground Integration Requirements Document (GIRD)	Code M, KSC
7. Ground Operations Safety	Code M, KSC
8. Flight Certification	Code M, KSC
9. Payload Integration & Quality	Code M, JSC & KSC
10 Flight	Code M, KSC
11. Payload/Flight Support Operations	Code M, JSC
12. Landing/Retrieval - Payload Deintegration	Code M, KSC or Code M, Dryden
13. Flight Debriefing	Code M, JSC

[5]Abbreviations are defined and described in section 5.2., Appendix F.

by the National Space Transportation System (Code M) initiates appropriate support to fulfill the flight operations.

Payload Integration Plan (PIP) - This is the agreement between cu.. mer and NASA on the responsibilities and tasks which directly relate to the integration of the payload into the Space Transportation System (STS); it includes identification of tasks that NASA considers as standard and optional services.

Preliminary Design Review (PDR) - Review for experiment before full PIP and safety processes start.

Critical Design Review (CDR) - Design review that ensures the experiment is acceptable and PIP and safety processes have been completed.

Annexes to PIP -

1. Payload Data Package
2. Flight Planning
3. Flight Operations Support
4. Command and Data
5. Payload Operations Control Center (POCC) Requirement
6. Orbiter Crew Compartment
7. Training (if required)
8. Launch Site Support Plan
9. Payload Interface Verification Summary

Launch Site Support Plan (LSSP) - Document completed by a NASA-supplied Launch Site Support Manager at KSC who receives and coordinates the launch and landing requirements of the users. This includes launch site payload processing, inspection, quality control, installation, and retrieval on landing.

Ground Integration Requirements Document (GIRD) - Document that the experimenter uses to specify all of the facilities needed during the preflight integration of the experiment from NASA at KSC.

5.8 Payload Integration Process

The following three lists indicate management and technical support teams, documents, and an overview of responsibilities for a Shuttle middeck experiment.

A. Management and Technical Support

Payload Mission Manager—Serves as single point of contact between the customer and the STS for technical integration of the payload to the STS.

Engineering Working Groups—The STS and customer will support the Engineering Working Groups (Avionics, Thermal, Structural/ Mechanical/Materials, Crew Compartments) as required to: define technical interface requirements; identify and define engineering tasks or analyses; develop the payload STS ICD.

Operations Working Groups—The STS and customer will support the Operations Working Groups (Ground, Flight Operations, Flight Planning) as required to: define operational requirements, exchange data required for payload operations.

B. Payload Integration Plan Document Annexes

Flight Planning
- Crew activities plan/event sequence
- Power, attitude, thermal profile
- Trajectories/launch windows

Payload Data Package
- Sequenced mass properties
- Configuration drawings
- RF radiation data

POCC Requirements
- Vol I - JSC POCC requirements
- Vol II - MCC to remote center interfaces

Command and Data

Crew Compartment Stowage/Installation

Launch Site Support Plan
- Process plan
- Facilities and services
- Checkout procedures

Training
- Flight crew
- Ground crew

- Integrated simulations

Flight Operations Support
- Operational plan
- Flight operations decision
- Data exchange timeliness
- Procedures

Interface Verification
- Interface verification matrix ICD
- Unique verification requirements

C. Overview of Responsibilities

Customer	NASA
• Submit Form 100	
• Define payload requirements as input to PIP	• Develop PIP to reflect payload requirements
• Suport development of ICD	• Develop ICD
• Submit safety review data	• Conduct safety revies
• Provide PIP annex data	• Review and publish PIP annexes
• Support CIR (user option)	• Conduct CIR
• Support IH/SR (user option)	• Conduct IH/SR
• Support ground operations review (GOR)	• Conduct GOR
• Support flight operations review (FOR)	• Conduct FOR
• Certify payload compatiblity	• Verification analysis
• Support flight readiness review (FRR)	• Conduct FRR
• Support flight operations during mission	• Conduct mission

6. NASA Budgets for Microgravity

The Office of Space Science and Applications annual budget has typically been about $1.5 billion over the past few years. MSAD has received increasing portions of this relatively fixed amount, and its share (typically around 2 percent of this figure) has at least doubled over the last five years, partly owing to encouragement by the

Congress and the Administration. The FY 1987 amount, $39.4 million, has nearly doubled for FY 1988, including an augmentation of $12.4 million for "Advanced Technology Development." The Dunbar Report recommended scaling this figure up to meet realistically the anticipated demands of microgravity research; namely, amounts suggested for FY 1987, 1988, and 1989 are $60, $150, and $200 million, respectively.

The Office of Commercial Programs budget for microgravity-related activities is comparable to that of OSSA, but exact amounts are difficult to identify owing to the admixture of other commercial space activities. About $10 million/year is dedicated to Centers for the Commercial Development of Space that have microgravity research emphases; a similar amount is dedicated to hardware development and sub-orbital rocket flight purchases; and about the same amount again is used for the promotion and administration of microgravity-related commercial ventures.

The Office of Aeronautics and Space Technology (OAST, Code R) accepts substantial responsibility for technology development, and its intra- and extramural programs related to microgravity, while not easily identifiable, are budgeted to a level comparable to that of the other two offices, namely $20-$30 million per year.

Large increments for the future have been recommended only for the OSSA efforts so far, and the OAST and OCP microgravity budgets are expected to be relatively stable. The proposed budgets of OSSA and OCP relevant to microgravity are given in Tables F-2 and F-3.

TABLE F-2 NASA Office of Space Science and Applications, Summary of Resources Requirements for the Materials Processing in Space Program

Funding Category	1986 Actual	1987 Amended Budget	1987 Current Estimate	1988 Budget Estimate
		(Thousands of Dollars)		
Research and analysis	12,100	12,900	13,900	14,400
Micrograv. Shuttle/Sta. payloads	18,900	26,500	34,000	31,500
Total	31,000	39,400	47,900	45,900
Distribution of Program Amount by Installation				
Johnson Space Center	2,274	2,505	3,255	3,013
Marshall Space Flight Center	6,447	10,829	13,429	12,804
Lewis Research Center	7,843	8,843	11,593	10,633
Langley Research Center	1,278	1,165	1,965	1,906
Jet Propulsion Laboratory	7,199	8,807	11,407	11,052
Headquarters	5,959	7,251	6,251	6,492
Total	31,000	39,400	47,900	45,900

TABLE F-3 Office of Commercial Programs, Summary of Resources Requirements for the Commercial Use of Space

Funding Category	1986 Actual	1987 Amended Budget (Thousands of Dollars)	1987 Current Estimate	1988 Budget Estimate
Commercial Applications R&D	12,940	22,600	22,600	31,000
Commercial Development Support	3,280	3,000	3,000	4,700
Total	16,220	25,600	25,600	35,700
Distrib. of Program Amount by Installation				
Johnson Space Center	150	560	560	1,040
Kennedy Space Center	50	---	---	---
Marshall Space Flight Center	4,334	6,350	6,350	11,430
National Space Technology Labs.	236	110	110	300
Goddard Space Flight Center	40	890	890	1,000
Jet Propulsion Laboratory	190	---	---	---
Ames Research Center	168	280	280	580
Langley Research Center	450	820	820	1,340
Lewis Research Center	1,294	1,170	1,170	1,940
Headquarters	9,308	15,420	15,420	18,070
Total	16,220	25,600	25,600	35,700

7. Recent Organizational Recommendations and their Implementation

The Dunbar Report contained ten recommendations:

1. *Optimize existing flight opportunities by establishing the Shuttle and Space Station as a national resource with experiment review boards and the development of multi-user hardware.*

2. *Increase flight opportunities and utilize the full range of microgravity opportunities, especially Shuttle middeck and Spacelab, "MSL's" (Materials Science Laboratory) pallets in the payload bay, Industrial Space Facility of SII/Westinghouse, extended Shuttle flights, and expendable launch vehicles.*

3. *Establish a stronger microgravity materials science program with research administered primarily in MSAD and improved coordination among NASA Offices managing microgravity research.*

4. *Maintain a broad-based science research program in which all of the (currently 6) disciplines continue to participate.*
5. *Increase hardware and technology development programs including generic instrumentation and "facilities-grade" hardware.*
6. *Develop an unambiguous, coherent policy for manifesting internationally competitive commercial programs.*
7. *Reinforce the Administration's and NASA's commitment to commercial use of STS and Space Station for microgravity research.*
8. *Increase the MSAD budget to $200 million by 1990 and increase the number of microgravity scientists and engineers at headquarters and at the field centers.*
9. *Establish a NASA strategic planning board for microgravity materials science involving, at least, all 6 offices involved in microgravity materials science.*
10. *Manifest Spacelab and Space Station development flights for 1990, 1992, and 1993, to create a round of flight opportunities that attracts users who expect reliability and to prepare U.S. microgravity scientists for the Space Station era.*

In addition, the report recommended several measures to relieve pressure on the STS facilities—namely, increased utilization of Shuttle bay pallets, free-flyer platforms, remotely controlled hardware, Get Away Special canisters, and sounding rockets.

Partly as a consequence of this and other reports, as well as other sources of advice, the NASA Deputy Administrator issued a series of memoranda on 12 June, 1987, which called for:

1. The appointment of a strong scientific Director of MSAD.
2. The manifestation of Secondary Payloads to accomplish specific NASA objectives.
3. Contracting for ELV launch services from the private sector.
4. Revised authority and responsibility for OCP.
5. A revised procedure for evaluating and processing Joint Endeavor Agreements.
6. Concentration of an increased portion of microgravity science project management in MSAD.

Rapid implementation of these memoranda was strongly suggested.

8. NACA as a Model

Commercialization of microgravity technologies requires effective cooperation among government, industry, and the academic sector. While government is often perceived to be an adversary of business in the United States, effective cooperation between government and industry is not unprecedented. One highly successful model for such cooperation is that which provided the foundation for the development of aeronautical technology in the United States—the National Advisory Committee on Aeronautics (NACA).

The NACA operated through a multiple tiered committee system which brought together experts from government, industry, and academia to work directly on the most important problems and enabling technologies underlying the establishment of U.S. leadership in aviation. This approach enabled senior expertise from all sectors to be pooled, permitting the entire spectrum of critical concerns (from practical economics to theoretical science) to be reflected in the solution of key problems and helping to assure the rapid and efficient transfer of results in a manner that aided U.S. industry first.

NASA's Microgravity Science and Applications Division currently has scientific panels in place, through a formally structured system with the Universities Space Research Association. Integration will be needed between the USRA Discipline Working Groups (7 scientific panels), which already represent industry, academe, and NASA, and the senior oversight board recommended in this report.

It would be appropriate for NASA to investigate NACA as a successful historical precedent to determine how a similar approach might be developed that would complement and enhance other existing mechanisms, such as the Centers for the Commercial Development of Space and the USRA Discipline Working Groups.